Source of Acquisition
NASA Goddard Space Flight Center

EXTENDED ABSTRACT for 2007 AAS/AIAA Astrodynamics Specialist Conference to ~~be held on August 19-23, 2007.~~

Abstract deadline is April 1, 2007.

Zero Gyro Kalman Filtering in the Presence of a Reaction Wheel Failure

Sun Hur-Diaz
Emergent Space Technologies, Inc., Greenbelt, MD

John Wirzburger
Honeywell Technology Solutions, Inc., Columbia, MD

Dan Smith
Lockheed Martin Mission Services, Greenbelt, MD

Mike Myslinski
Honeywell Technology Solutions, Inc., Columbia, MD

SUMMARY (also condensed abstract for printed program)

Typical implementation of Kalman filters for spacecraft attitude estimation involves the use of gyros for three-axis rate measurements. When there are less than three axes of information available, the accuracy of the Kalman filter depends highly on the accuracy of the dynamics model. This is particularly significant during the transient period when a reaction wheel with a high momentum fails, is taken off-line, and spins down. This paper looks at how a reaction wheel failure can affect the zero-gyro Kalman filter performance for the Hubble Space Telescope and what steps are taken to minimize its impact.

BACKGROUND

To account for loss of gyros on the Hubble Space Telescope (HST), a Kalman filter has been designed that processes measurements from the magnetometer, coarse sun sensors, and any number of gyros, including zero. In the absence of three-axis rate information from the functional gyros, a high fidelity dynamics model had to be utilized to achieve the Kalman filter performance required for both science and safe mode operations.

HST control actuation is achieved through a set of four redundant reaction wheels. In normal operations, each individual wheel tachometer provides accurate speed information

which the Kalman filter processes to determine the total system momentum as well as the torque provided by the reaction wheels. This is used in the dynamics model for the time update computation of the Kalman filter. In the event a reaction wheel fails and is powered off due to a safe mode test response, the tachometer output of the unpowered wheel will be erroneous. For a reaction wheel failure at high speeds, the resulting error in momentum calculation causes large errors in the Kalman filter position and rate estimates. The filter is especially susceptible during orbit nights when only the magnetometer measurement is available.

Figure 1 shows the simulation result of a case where the zero-gyro Kalman filter diverges with the initial speed of the failed wheel around 2500 rpm. The top plot shows the magnitude of the position estimate error along with the orbit night flag. The bottom plot shows the error in the knowledge of the failed wheel's speed. Note that the position estimate error decreases as the wheel speed error decreases.

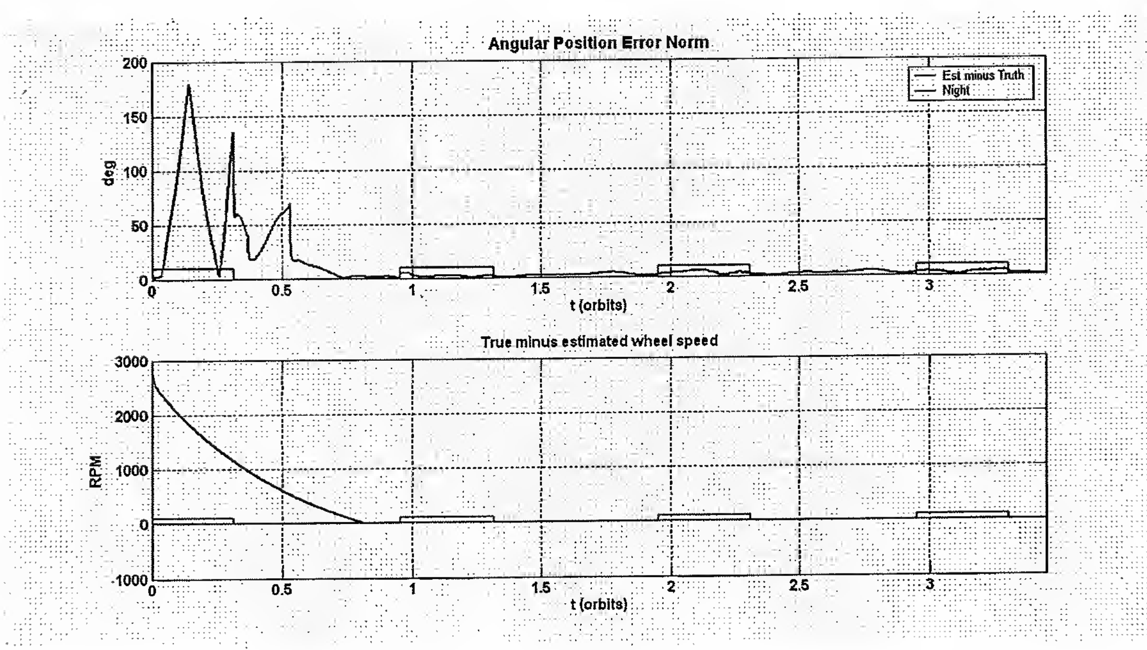

Figure 1.

METHODOLOGY

To minimize these errors, a model of the wheel deceleration after power off was developed based on data provided by the reaction wheel manufacturer. In addition, to minimize errors in this model, the conditions at the start of the deceleration had to be captured accurately. This was done by an accurate model of the wheel torque output and a more sensitive safe mode test to catch any failures early. These three mitigation steps improved the performance of the Kalman filter during the transient spin-down period of a failed wheel.

Figure 2 shows the position estimate error of the same case, but with the models of the wheel momentum estimators during powered and unpowered states and the new safe mode test in place. The wheel speed error has dropped significantly and so has the Kalman filter position estimate error.

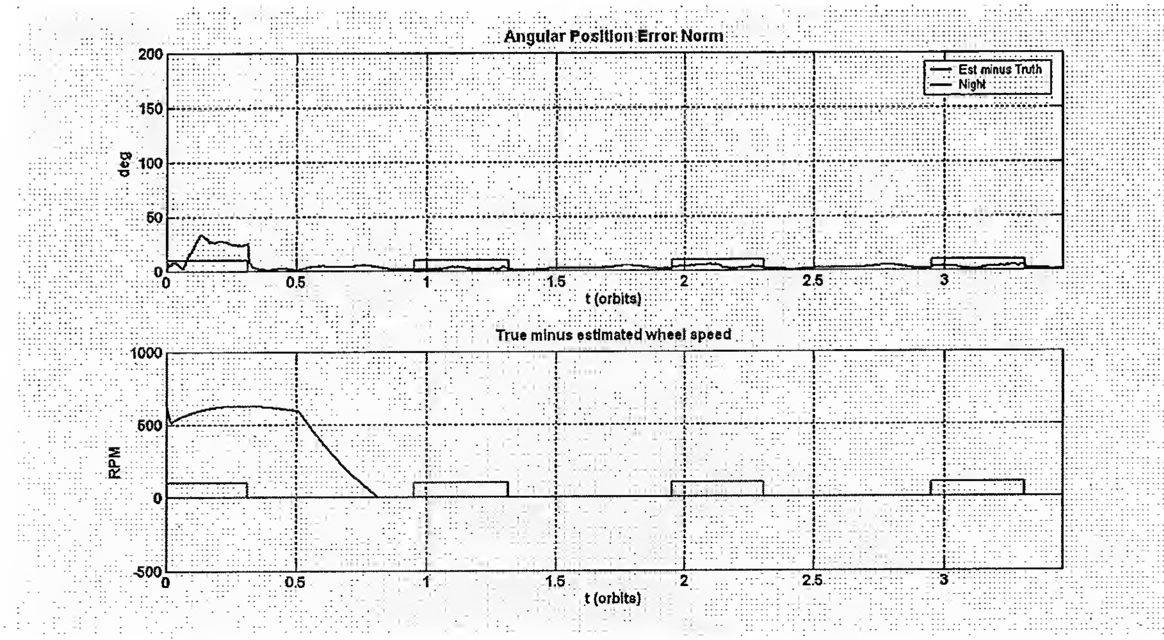

Figure 2.

In spite of these models, however, the uncertainty on the wheel speed can still be several orders of magnitude higher than the measurement accuracy of the tachometer. The larger uncertainty is taken into account by increasing the Kalman filter process noise during the spin-down period. Then the nominal value of the process noise is reinstated once the estimate of the wheel speed reaches within a tolerance of zero. The filter contains measurement innovations checks as well as convergence checks based on the state covariance and measurement residuals. So as not to erroneously trip the convergence monitor limit or to reject good measurements, thresholds for these checks had to be increased as well.

Figure 3 show the position estimate error with the added switching logic in the process noise and the covariance, innovations, and residual thresholds where the process noise covariance was increased by roughly two orders of magnitude during the spin-down period. This provided additional improvement in the Kalman filter performance as shown in the first plot.

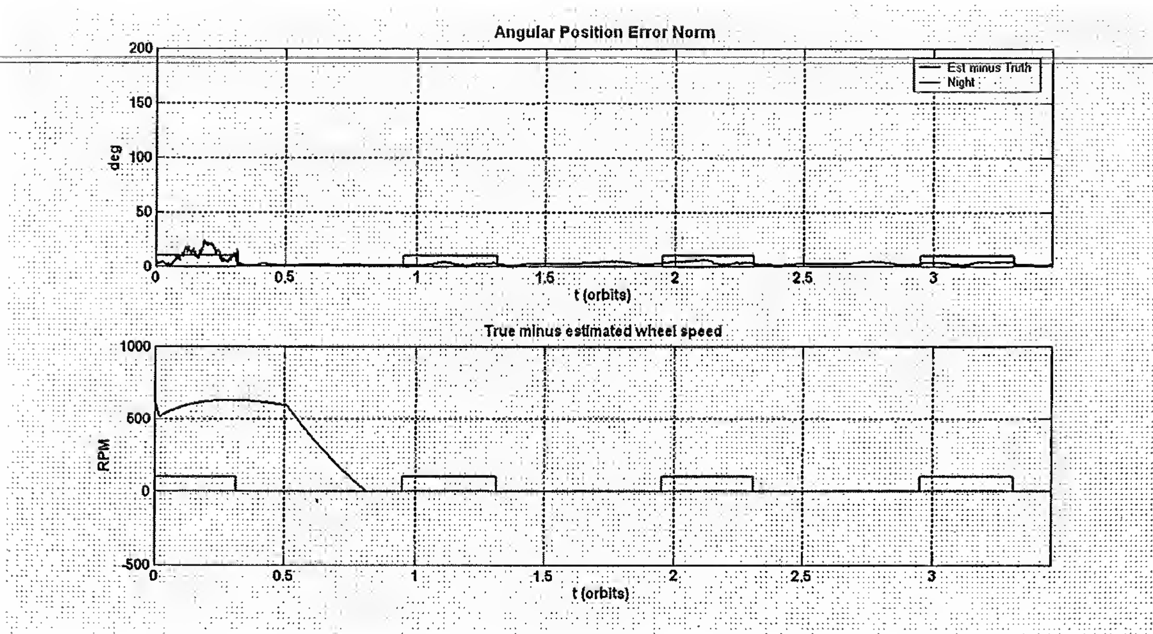

Figure 3.

CONCLUSIONS

A reaction wheel failure can cause a gyro-less Kalman filter to diverge during the period when the failed wheel is spinning down and there is no input from the tachometer. Models of the reaction wheel during its powered and unpowered states as well as a new safe mode test to capture the failure early were shown to improve performance by increasing the accuracy of the dynamics model. Additionally increasing the process noise and managing the innovations, residuals, and covariance checks during this period to account for the increased uncertainty in the dynamics model improved the Kalman filter performance even further.